How solar accelerated electron beams vary as a function of distance from the Sun

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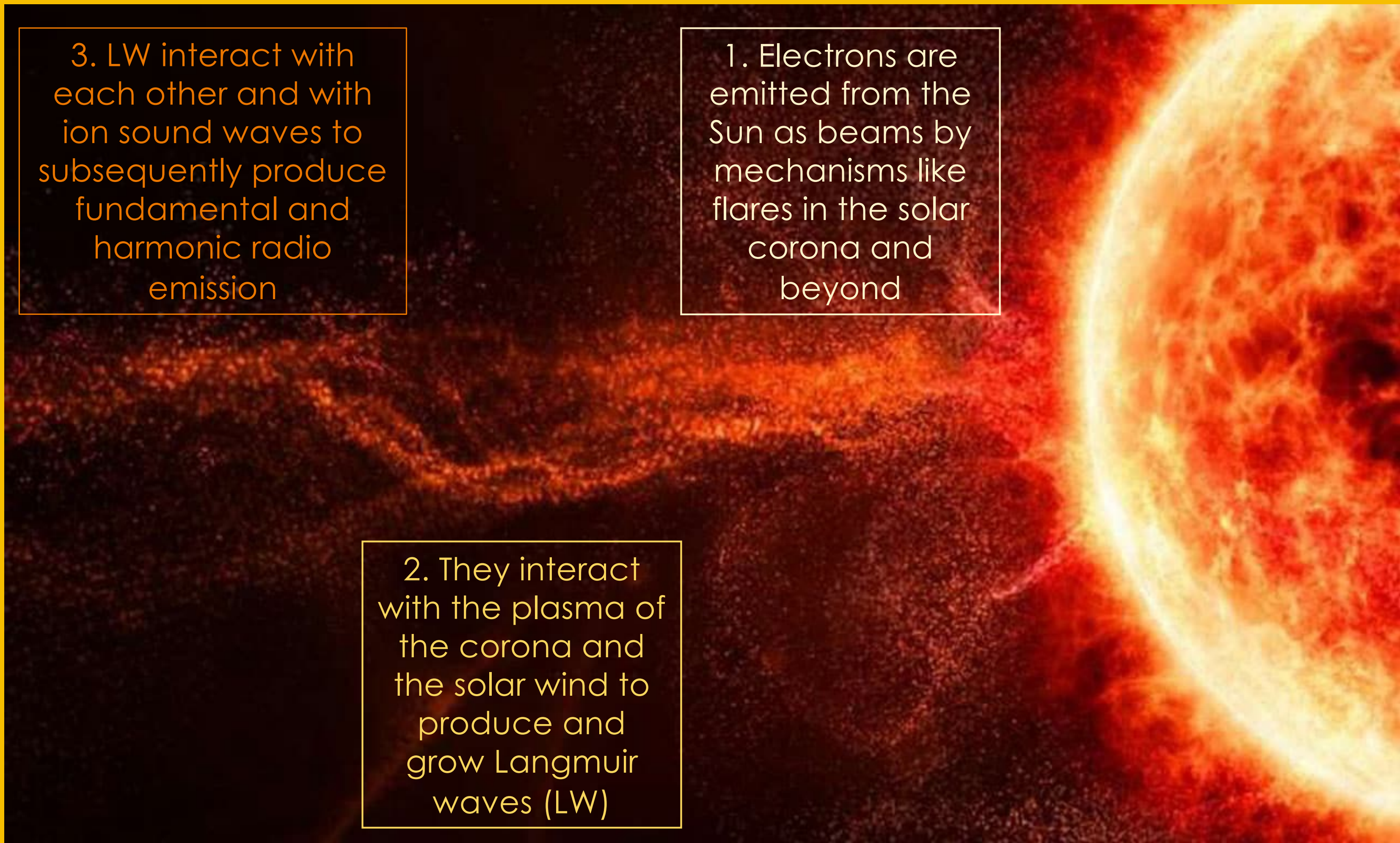
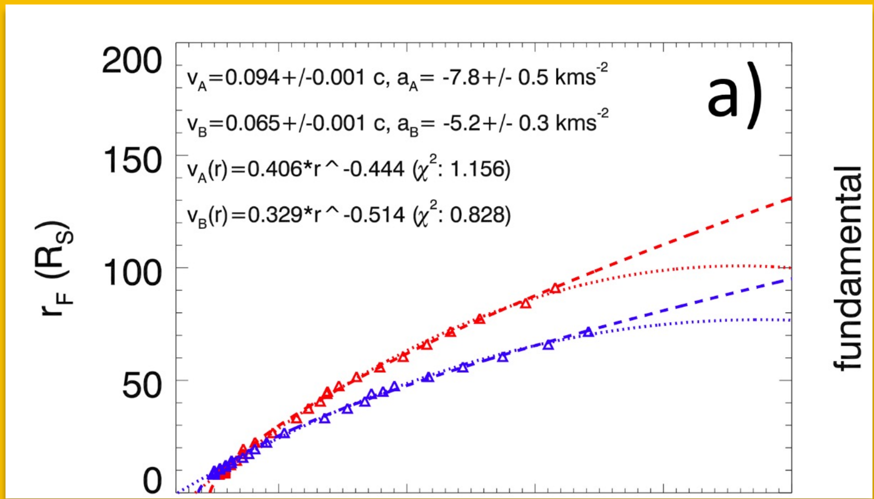
What happens around the Sun?

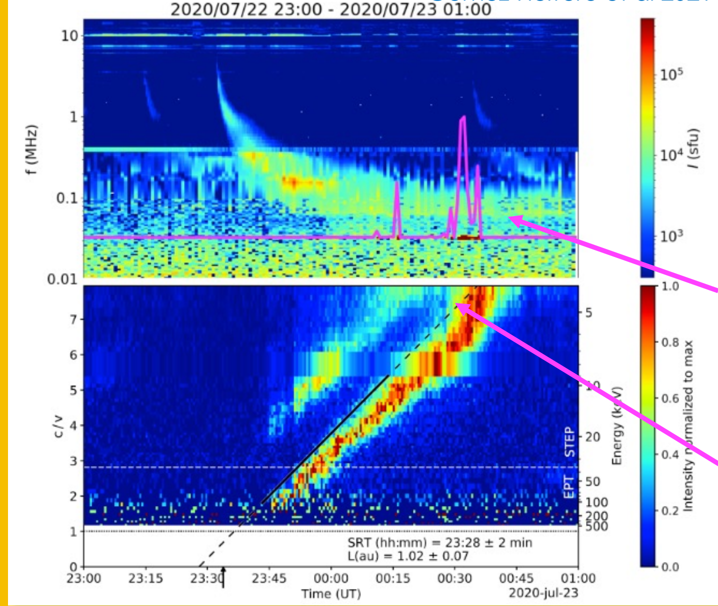


Previous work and why we care



Krupar et al 2015

Gomez-Herrero et al 2021



LW growing above the thermal level

arriving with the 5kev electrons

- Type IIIs observations show electrons generating LW get smaller in energy as function of distance from the Sun (Krupar et al 2015)
- If the electron energy stayed constant as the beam propagated away from the Sun we would see a straight line fit to the data

- LW seem to arrive simultaneously to the 5kev electrons (c/v = 6).
- This indicates these are the electrons interacting with the LW at 0.6AU
- Black line is the estimate of electron onset times (Gomez Herrero et al 2021)
- Estimate valid at high velocities but breaks at low energies (diffusion)

Electron beam-plasma interactions: a Quasilinear approach

What is the maximum velocity responsible for Langmuir wave growth as a function of distance from the Sun?

Expansion of the beam in space
Collisions
Source function
Group velocity of LW
Refraction of LW
Landau damping
Collision
Thermal level of LW

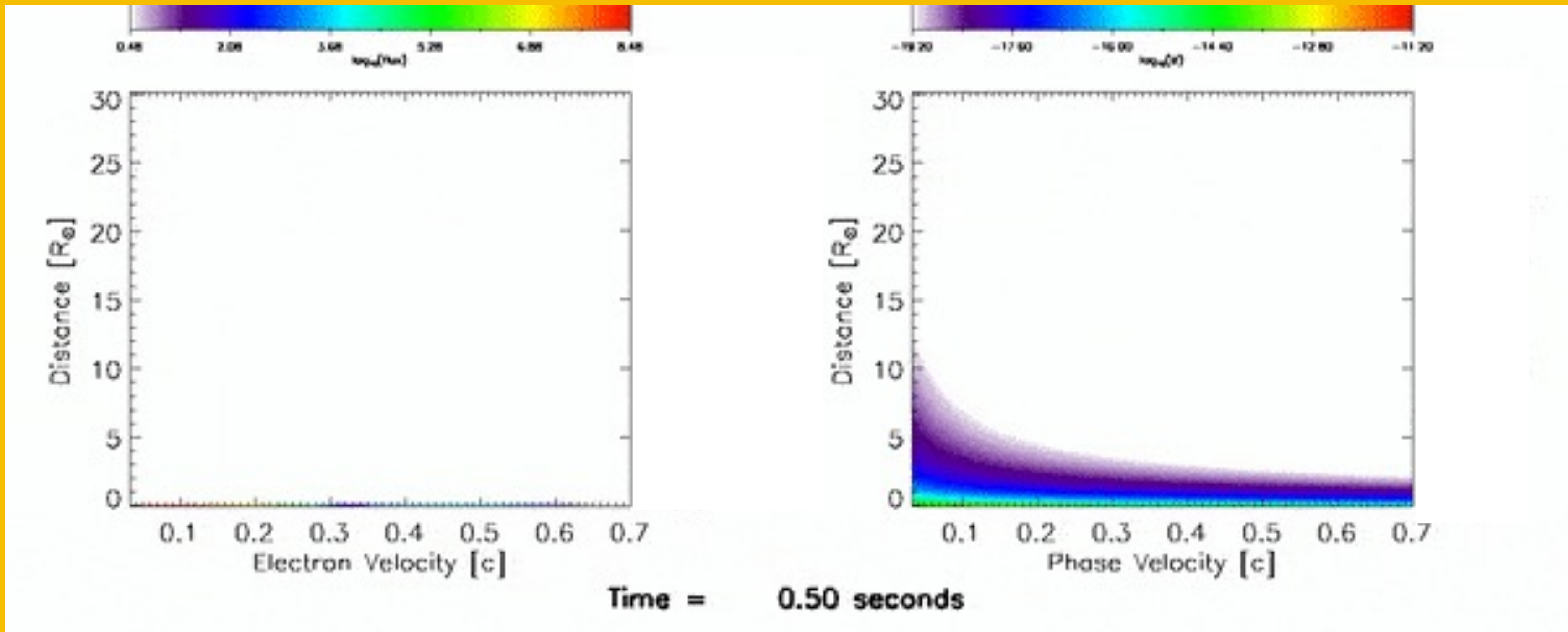
$$\frac{\partial f}{\partial t} + \frac{v}{M(r)}\frac{\partial}{\partial r}M(r)f = \frac{4\pi^2 e^2}{m_e^2}\frac{\partial}{\partial v}\left(\frac{W}{v}\frac{\partial f}{\partial v}\right) + \frac{4\pi n_e e^4}{m_e^2}\ln\Lambda\frac{\partial}{\partial v}\frac{f}{v^2} + S(v,r,t) \quad (1)$$

$$\frac{\partial W}{\partial t} + \frac{\partial \omega_L}{\partial k}\frac{\partial W}{\partial r} - \frac{\partial \omega_{pe}}{\partial r}\frac{\partial W}{\partial k} = \frac{\pi\omega_{pe}}{n_e}v^2 W\frac{\partial f}{\partial v} - (\gamma_L + \gamma_c)W + e^2\omega_{pe} v f \ln\frac{v}{v_{Te}}, \quad (2)$$

Reid and Kontar 2013

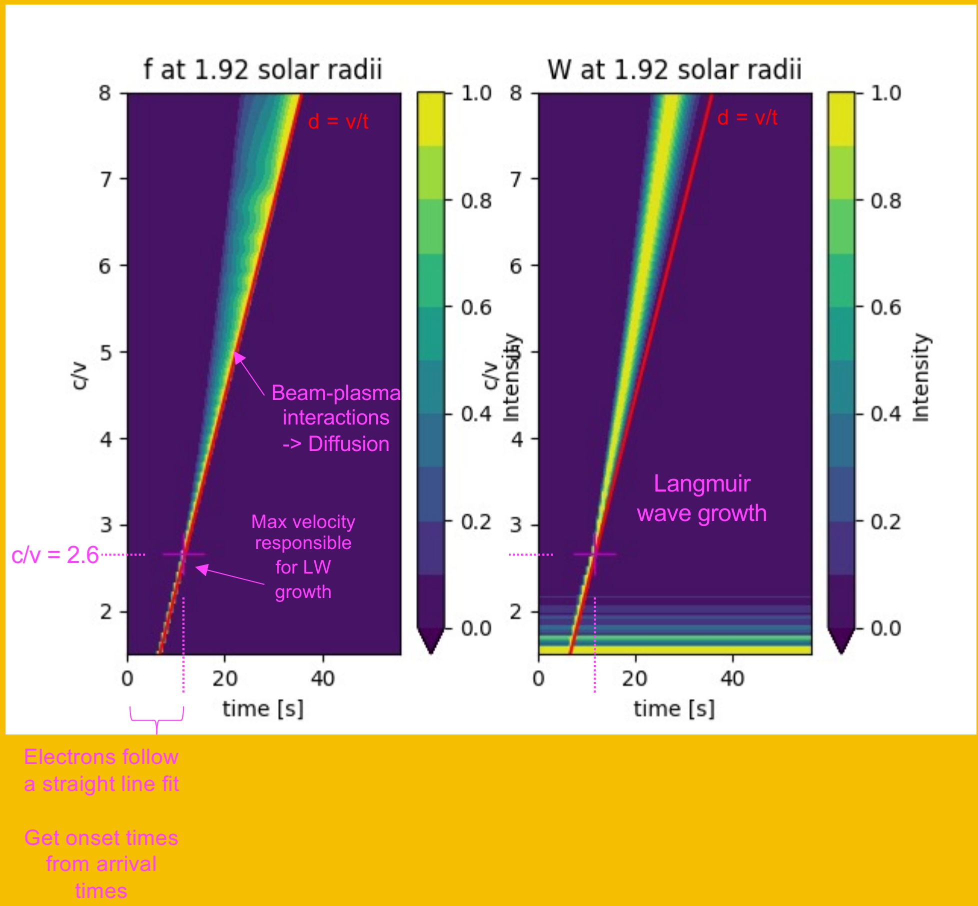
- Injection of a power law in velocity space of electrons at the Sun
- These equations represent the propagation of the beam in space as it interacts with the background plasma

Electron beam-plasma interactions: a Quasilinear approach



Phase space (velocity-distance) contour plot of the electron distribution function and the spectral energy density of LW

Replicating the **Gomez-Herrero et al 2021** plot at 1.92 solar radii



- The simulation shows that LW are being grown at c/v = 2.6
- Closer to the Sun we see that LW resonate with higher energy electrons, why?
- Close to the Sun the beam follows magnetic flux tubes: little expansion, high electron density, higher velocity electrons interact with the plasma

Replicating the **Gomez-Herrero et al 2021** plot at 13.92 solar radii

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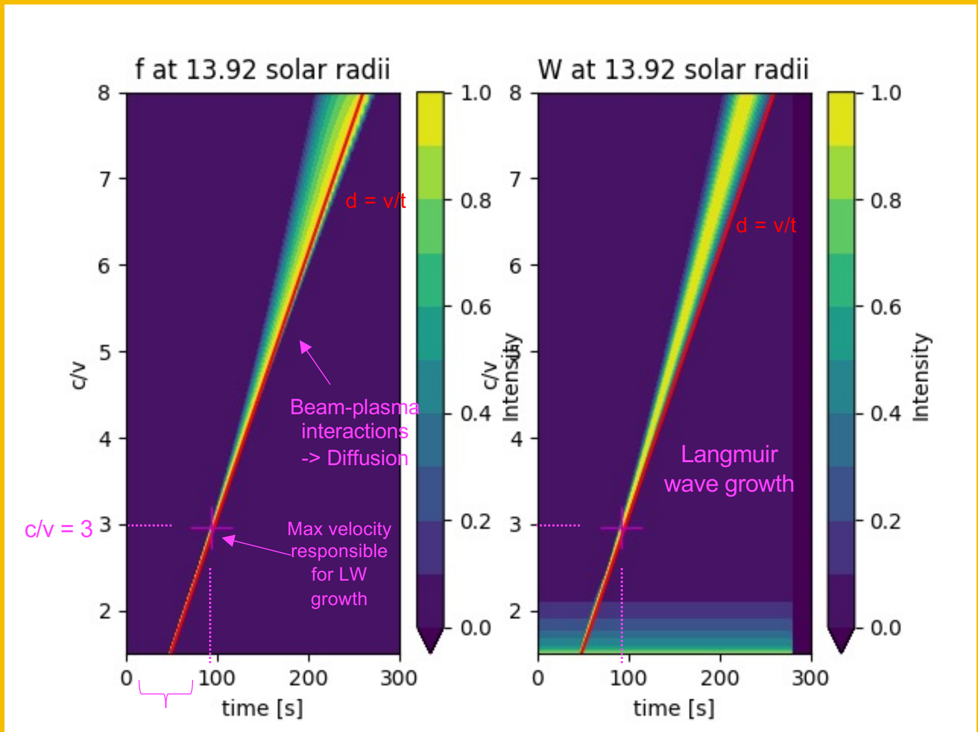

Electrons follow a straight line fit

Get onset times from arrival times

- We want to use the higher energy electrons for onset times but this is not valid anymore for lower energy electrons.
- We observe that the maximum velocity responsible for LW growth decreases as a function of distance from the Sun.
- We observe diffusion in velocity space from c/v = 3 then there is an error on arrival times

Constant velocity onset (blue) vs actual (dotted) electron arrival times at 1.92 and 13.92 solar radii

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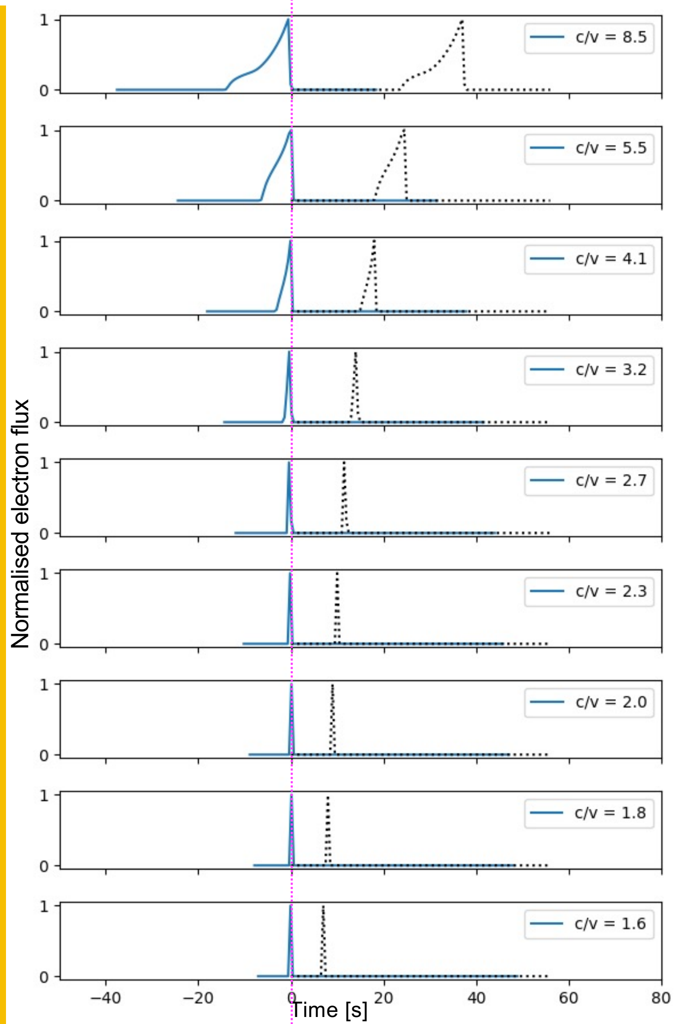
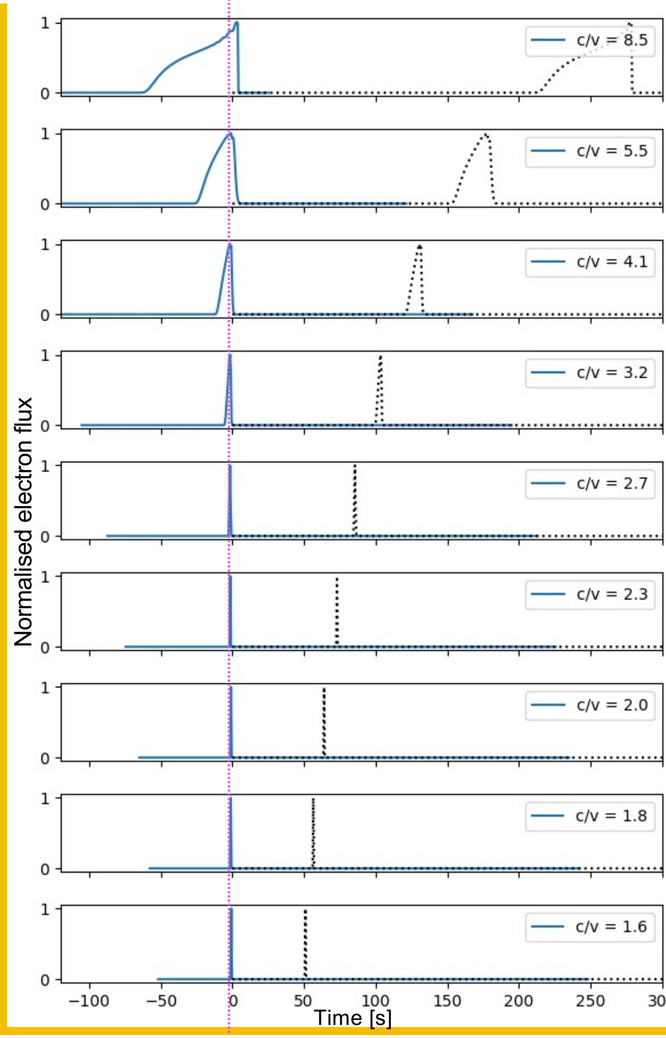
- Electrons arrive earlier than expected: why?
  - ➢ Deceleration during the propagation
  - ➢ Diffusion in electron velocity space
  - ➢ Discrepancy in arrival times only at low velocities/energies
- Can we assume the electron path to be scatter free?
- Net energy loss – reduction in V_{ph} of LW





Conclusions and future work

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- The higher energy electrons interact with the Langmuir waves closer to the Sun
- This is due to the higher energy density of electrons close to the Sun

- Next I will investigate the role of the spectral index of the velocity distribution, the beam density, and the plasma density and how it affects which energy electrons interact with the LW
- My next project will compare the results of these simulations to PSP and SolO data